Chapter One

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IN THIS CHAPTER:

Exercise Physiology

By John P. Porcari and Carl Foster

The structure and function of the human body allow an extraordinarily wide range of possible movements requiring very complex interactions of neuromuscular coordination and metabolism. For example, a pole vaulter needs to be able to couple the coordination and agility to maneuver over the crossbar with the explosive burst of energy needed to sprint down the runway. At the other extreme, an ultramarathoner needs to be able to generate low levels of energy repetitively for prolonged periods of time.

Exercise Physiology

The study of **exercise physiology** allows an understanding of how the body responds to the varied demands placed on it by exercise. It is essential that the group fitness instructor understands the basics of exercise physiology so that he or she can design safe and effective exercise programs.

Physical Fitness

Before discussing the specific effects of exercise on the body, it is important to realize that there are several areas that contribute to overall "**physical fitness**" and, hence, different body systems that need to be trained appropriately. Physical fitness is a complex concept that has different meanings to different people. In this manual, physical fitness refers to the **capacity** of the heart, blood vessels, lungs, and muscles to function at a high level of efficiency. A person who is physically fit has an enhanced functional capacity that allows for a high quality of life. Although a somewhat vague phrase, quality of life generally implies an overall positive feeling and enthusiasm for life and the ability to do enriching and enjoyable activities without fatigue or exhaustion from routine and required activities. A high level of physical fitness allows people to comfortably perform their required daily tasks and enables them to participate in additional pleasurable activities for personal enjoyment. As physiological or functional capacity increases, one's capacity for physical activity or exercise also increases. In other words, a person can lift heavier weights or run farther or faster—in short, can participate in more strenuous activities. Being physically fit makes possible a lifestyle that the sedentary cannot enjoy. Increased physical fitness is often reflected by physiological adaptations, such as a lowered heart rate during a standardized exercise test or an improved ability to mobilize and use body fuels. A high level of physical fitness implies optimal physical performance and good health.

There are five major components of physical fitness. It should be noted that the components are health-related as opposed to skill-related. The development of a high degree of **motor skill** is sometimes confused with physical fitness, but these two attributes are not necessarily related. A highly skilled person may have a low level of physical fitness, and the reverse may also be true. Motor skill (sometimes referred to as motor performance or motor fitness) is thought to be related to such attributes as **agility, balance, speed, power** and **coordination**—terms that defy precise definition but can profoundly affect a person's overall health or quality of life (e.g., balance deficits have been consistently linked to a greater risk of falling in older adults). Additional information on thsese skill-related components of fitness can be obtained on the ACE website (www.acefitness.org/FitFacts).

The five components of physical fitness are as follows:

1. **Muscular strength** is the maximal force a muscle or muscle group can exert during contraction. Muscular strength is essential for normal everyday functioning, and is required to lift and carry objects (e.g., groceries, suitcases) in daily life. Adequate muscular strength may become even more important as people age. In many cases, for instance, the elderly are not able to walk up stairs or get up out of a chair due to inadequate strength in the lower extremities.

2. **Muscular endurance** is the ability of a muscle or muscle group to exert force against a resistance over a sustained period of time. Muscular endurance is assessed by

measuring the number of times (**repetitions**) that a given task can be performed without fatigue. Many everyday activities require a significant amount of muscular endurance (e.g., walking up stairs, shoveling snow).

3. **Cardiovascular** or **cardiorespiratory endurance** (sometimes referred to as **aerobic power** or **aerobic fitness**) is the capacity of the heart, blood vessels, and lungs to deliver oxygen and nutrients to the working muscles and tissues during sustained exercise and to remove the metabolic waste products associated with fatigue. Efficient functioning of the cardiorespiratory system is essential for physical activities such as walking, running, swimming, and cycling. The performance of regular, moderately intense aerobic exercise is the key to developing and maintaining an efficient cardiorespiratory system.

4. **Flexibility** is the ability to move joints through their normal full **range of motion (ROM)**. An adequate degree of flexibility is important to prevent musculoskeletal injuries and to maintain correct body posture.

5. **Body composition** is the makeup of the body considered as a two-component model: **lean body mass** and **body fat**. The lean body mass consists of the muscles, bones, nervous tissue, skin, blood, and organs. These tissues have a high metabolic rate and make a direct and positive contribution to energy production during exercise. The primary role of body fat, or **adipose tissue,** is to store energy for later use. Body fat does not normally contribute in a direct sense to exercise performance. Body fat is further classified into **essential body fat** and storage body fat. Essential body fat is that amount of fat thought to be necessary for maintenance of life and reproductive function; 2 to 5% body fat is generally thought to be essential for men, and 10 to 13% for women. (Percent body fat refers to the percentage of the total body weight that is fat.) Storage fat is contained in the fatty deposits or fat pads found under the skin (**subcutaneous fat**) and deep inside the body (**internal fat**). A large amount of storage fat is considered excess fat and results in the condition referred to as **obesity.**

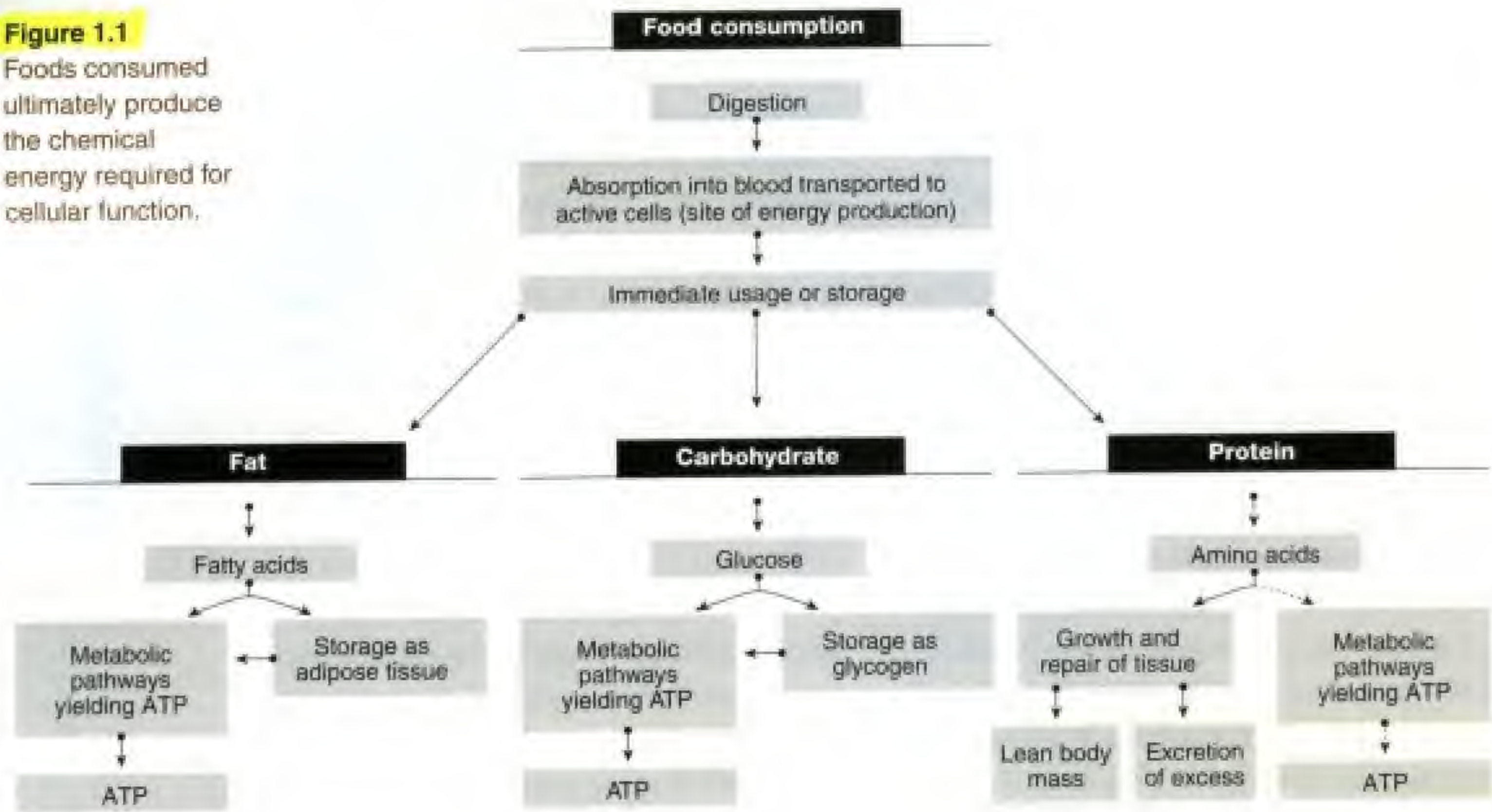
Bioenergetics of Exercise

The body's cells require a continuous supply of energy to function. Ultimately, the food people eat supplies this energy. However, the cells do not directly use the energy contained in the food. Rather, they need a chemical compound called **adenosine triphosphate,** or **ATP.** ATP is the immediately usable form of chemical energy needed for all cellular function, including muscular contraction.

Foods are made up of carbohydrates, fats, and proteins. The process of digestion breaks these nutrients down to their simplest components (**glucose, fatty acids,** and **amino acids**), which are absorbed into the blood and transported to metabolically active cells, such as muscle, nerve, or liver cells. These components either immediately enter a metabolic pathway to produce ATP or are stored in body tissues for later use.

For example, excess glucose will be stored as **glycogen** in muscle or liver cells. Fatty acids that are not immediately used for ATP production will be stored as adipose tissue (body fat). In contrast, relatively little of the protein (amino acids) a person eats is used for energy production. Instead, it is used for the growth or repair of cellular structures or is excreted in waste products. Figure 1.1 summarizes the fate of carbohydrates, fats, and proteins.

Figure 1.1
Foods consumed ultimately produce the chemical energy required for cellular function.

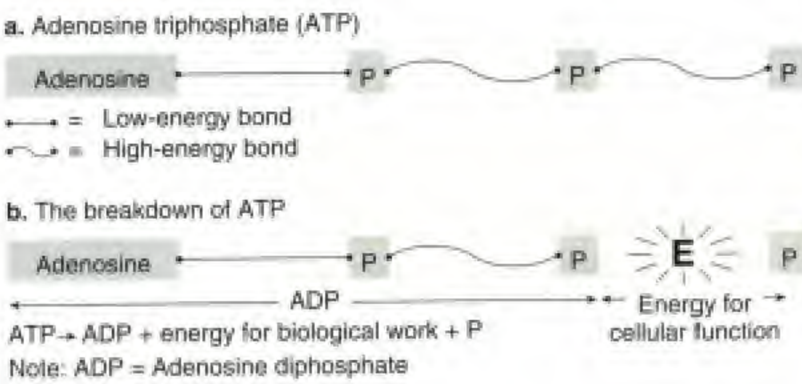


Stored ATP—The Immediate Energy Source

ATP is a complicated chemical structure made up of a substance called adenosine and three simpler groups of atoms called phosphate groups (P). Special high-energy bonds exist between the phosphate groups (Figure 1.2a). Breaking the terminal phosphate bond releases energy (E) that the cell uses directly to perform its cellular function (Figure 1.2b). The specific cellular function performed depends on the type of cell. In a muscle cell, the breakdown of ATP allows the mechanical work known as muscular contraction. If ATP is not available, muscle contraction stops.

While ATP can be stored within the cells, the amount stored and immediately available for muscle contraction is extremely limited, sufficient for only a few seconds of muscular work. Therefore, ATP must be continuously resynthesized. ATP can be resynthesized in several ways: immediately by the phosphagen system, somewhat more slowly with the **anaerobic** production of ATP from carbohydrate, or still more slowly with the aerobic production of ATP from either carbohydrate or fat. All three energy pathways are always active, but their relative activity varies from movement to movement, depending on the momentary level of muscular activity.

Figure 1.2
Breakdown of the ATP molecule



The Phosphagen System

Creatine phosphate (CP) is another high-energy phosphate compound found within muscle cells. Together, ATP and CP are referred to as the **phosphagens.** When ATP is broken down for muscular contraction, it is resynthesized very quickly from the breakdown of CP. The energy released from breaking the high-energy phosphate bond in CP is used to reconstitute ATP from **adenosine diphosphate (ADP)** and P (the phosphate group broken off from ATP), by-products of the initial reaction. This process is shown in Figure 1.3.

The total amount of ATP and CP stored in muscle is very small, and thus the amount of energy available for muscular contraction is extremely limited. There is probably enough energy available from the phosphagens for only about 10 seconds of all-out exertion. However, this energy is instantaneously available for muscular contraction, and therefore is essential at the onset of physical activity and during short-term, high-intensity activities such as sprinting, performing a weight-lifting movement, or leaping across a stage.

Anaerobic Production of ATP From Carbohydrate

The anaerobic production of ATP from carbohydrate is known as **anaerobic glycolysis. Anaerobic** literally means "without the presence of oxygen," and **glycolysis** refers to the breakdown of glucose or its storage form, glycogen. Thus, anaerobic glycolysis is a metabolic pathway that does not require oxygen, the purpose of which is to transfer energy contained in glucose (or glycogen) to the formation of ATP.

Anaerobic glycolysis is capable of producing ATP quite rapidly and thus is required when energy (ATP) is needed to perform activities requiring large bursts of energy over somewhat longer periods of time than the phosphagen system allows. This metabolic pathway occurs within the cytoplasm of the cell and involves the incomplete breakdown of glucose (or glycogen) to a simpler substance called pyruvate. If exercise intensity is very high and adequate amounts of oxygen are not available, **pyruvate** is converted into **lactate,** as indicated in Figure 1.4a. Lactate may be transported out of the active cell and used for energy by other cells in the body.

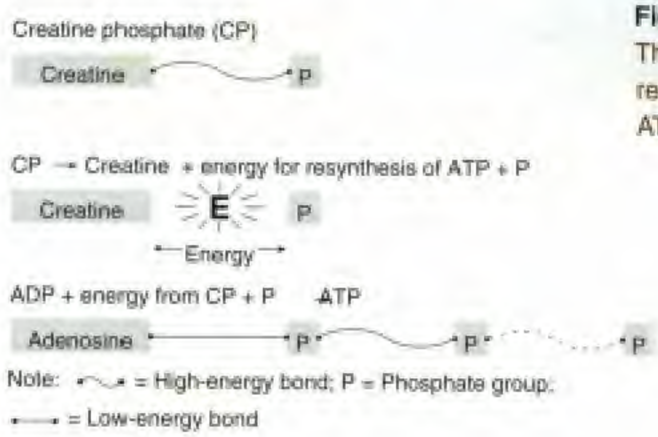


Figure 1.3
The immediate resynthesis of ATP by CP

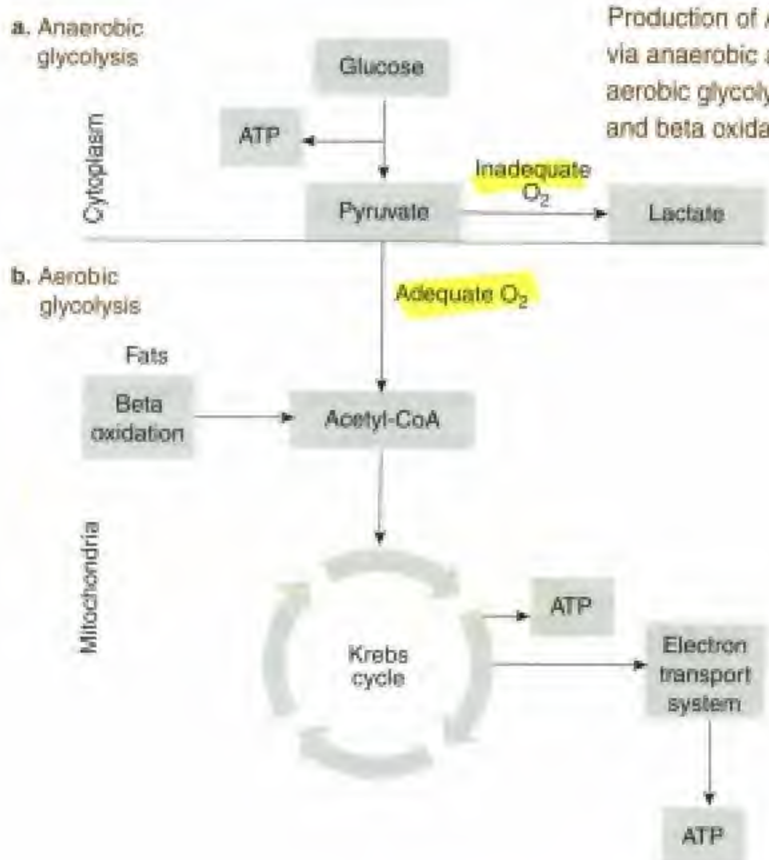


Figure 1.4
Production of ATP via anaerobic and aerobic glycolysis and beta oxidation

The formation of lactate poses a significant problem because it is associated with changes in muscle pH (acidity) and eventual muscle fatigue when it accumulates in large amounts. If the removal of lactate by the circulatory system cannot keep pace with its production in the active muscles, temporary muscle fatigue may occur with painful symptoms, usually referred to as "the burn." Thus, anaerobic glycolysis can only be used to a limited extent during sustained activity, but provides the main source of ATP for high-intensity exercise lasting up to a maximum of approximately three minutes.

Aerobic Production of ATP From Carbohydrate or Fat

The aerobic production of ATP is used for activities requiring sustained energy production. Since **aerobic** literally means "in the presence of oxygen," aerobic metabolic pathways require a continuous supply of oxygen delivered by the circulatory system. Without oxygen, these pathways cannot produce ATP.

The metabolic pathway, called **aerobic glycolysis** or **oxidative glycolysis,** occurs within highly specialized cell structures called the **mitochondria.** Mitochondria, which are often called the powerhouses of the cell, contain specific enzymes (**oxidative enzymes**) needed by the cell to utilize oxygen. This highly efficient metabolic process is limited mainly by the capacity of the cardiorespiratory system to deliver oxygen to the active cells. When sufficient oxygen is available, pyruvate is converted into acetyl-CoA, which enters the Krebs cycle and the electron transport system, produces substantial amounts of ATP (Figure 1.4b), and produces CO_2 and H_2O as easily removable waste products.

Aerobic pathways are also available to break down fatty acids (the digested component of dietary fat) for the production of ATP. This metabolic pathway, called **fatty acid oxidation**, or **beta oxidation,** also occurs within the mitochondria and requires a continuous supply of oxygen (as does aerobic glycolysis). The aerobic metabolism of fat yields a very large amount of ATP; therefore, fat is said to have a high caloric density. A calorie is a unit of energy. Fat yields 9 kilocalories of energy per gram compared to 4 kilocalories of energy per gram of glucose. That is why body fat is such an excellent source of stored energy (and so hard to get rid of).

At rest, the body uses both glucose and fatty acids for energy production via aerobic pathways. The cardiorespiratory system can easily supply the oxygen necessary for this low rate of energy metabolism. With exercise, however, supplying the required amount of oxygen rapidly enough becomes more difficult. Because glucose metabolism requires less oxygen than fatty acid metabolism, the body will use more glucose for energy production and less fat as exercise intensity increases. Table 1.1 provides a summary and comparison of the aerobic and anaerobic systems of ATP production.

Training

The various energy systems adapt to repetitive stress, meaning that they demonstrate a training effect. There is evidence that the concentrations of CP and ATP present in the muscle increase with training, particularly following high-intensity training that is likely to cause depletion of the phosphagens. Similarly, there is evidence to suggest that high-intensity training increases both the ability to transport lactate out of the muscle and the ability to buffer acid metabolites. There are profound adaptations to aerobic training, due to both central

and peripheral changes. The ability of the heart to pump blood (cardiac output) increases, primarily as a result of an increase in stroke volume. The ability of the muscles to utilize oxygen to produce ATP also increases due to an increase in the number of mitochondria in the active muscles. Collectively, these changes result in an increase in an individual's aerobic capacity.

Muscles and Metabolism

Muscles are composed of several kinds of fibers that differ in their ability to utilize the metabolic pathways outlined above. **Fast-twitch (FT) fibers** are rather poorly equipped in terms of the oxygen delivery system, but have an outstanding capacity for the phosphagen system and a very high capacity for anaerobic glycolysis. Therefore, fast-twitch fibers are specialized for anaerobic metabolism. They are recruited by the nervous system predominantly for rapid, powerful movements such as jumping, throwing, and sprinting.

Slow-twitch (ST) fibers, on the other hand, are exceptionally well equipped for oxygen delivery and have a high quantity of aerobic, or oxidative, enzymes. Although they do not

Table 1.1
Comparison of Anaerobic and Aerobic Systems of ATP Production

Anaerobic System	Rate of ATP Production	Substrate(s)	Capacity of System	Major Limitation(s)	Major Use
Phosphagens (stored ATP & CP)	Very rapid rate	CP	Very limited ATP production	Very limited supply of CP	Very high-intensity, short-duration sprint activities. Predominates during activities of 1–10 seconds.
Anaerobic glycolysis (GLU → ATP + LA)	Rapid metabolic rate	Blood glucose Glycogen	Limited ATP production	Lactate by-product causes rapid fatigue	High-intensity, short-duration activities. Predominates during activities of 1–3 minutes.

Aerobic System	Rate of ATP Production	Substrate(s)	Capacity of System	Major Limitation(s)	Major Use
Aerobic glycolysis	Slow metabolic rate	Blood glucose Glycogen	Unlimited ATP production	Relatively slow rate of oxygen delivery to cells Glycogen storage	Lower-intensity, longer-duration endurance activities. Predominates during activities longer than 3 minutes.
Fatty acid oxidation	Slow metabolic rate	Fatty acids	Unlimited ATP production	Relatively slow rate of oxygen delivery to cells Large amount of O_2 needed	Lower-intensity, longer-duration endurance activities. Fatty acid oxidation predominates after about 20 minutes of continuous activity.

Note: ATP = Adenosine triphosphate; GLU = Glucose; LA = Lactate; CP = Creatine phosphate

have a highly developed mechanism for use of the phosphagens or anaerobic glycolysis, ST fibers have a large number of mitochondria and, consequently, are particularly well designed for aerobic glycolysis and fatty acid oxidation. Thus, ST fibers are recruited primarily for low-intensity, longer-duration activities such as walking, jogging, and swimming.

Most people have roughly equal percentages of both fiber types. Persons who excel in activities characterized by sudden bursts of energy, but who tire relatively rapidly, probably have a high percentage of fast-twitch fibers. Persons who are best at lower-intensity endurance activities probably have a large percentage of slow-twitch fibers. There are also a number of "intermediate" muscle fibers that have a fairly high capacity for both fast anaerobic and slow aerobic movements.

Muscle fiber distribution (fast twitch, intermediate, or slow twitch) is determined to a large extent by genetic makeup. This is not to say, however, that muscle fiber type is unresponsive to activity. All three types of muscle fiber are highly trainable; that is, they are capable of adapting to the specific metabolic demands placed on them. If a person engages regularly in low-intensity endurance activities, aerobic capacity will improve. Although all three types of muscle fiber will show some improvement in aerobic ability, the ST fibers will be most responsive to this kind of training and will show the largest improvement in aerobic capacity. If, on the other hand, short-duration, high-intensity exercise such as interval training is performed regularly, other metabolic pathways will be emphasized, and the capabilities of the FT fibers to perform anaerobically will be enhanced. ST fibers are less responsive to this kind of training.

It is important for group fitness instructors to have a thorough understanding of the different metabolic systems to develop specific exercise programs that will enable participants to achieve desired results. As discussed, exercise intensity and duration is directly related to the continuum of metabolic pathways and movement patterns. For example, including quick, explosive movements specific to the use of the phosphagens and anaerobic glycolysis in a workout will be ineffective if the goal of the exercise program is to develop cardiorespiratory endurance. This concept, known as **exercise specificity,** is one of the most important principles of exercise physiology.

The Neuromuscular System

Group fitness instructors need to understand how a motor skill is executed. Such an understanding requires a basic appreciation of the neuromuscular system, which includes both the nervous and musculoskeletal systems. The nervous system is responsible for coordinating movement, while the musculoskeletal system is responsible for carrying out the movement.

Basic Organization of the Nervous System

The basic anatomical unit of the nervous system is the **neuron,** or nerve cell. There are two kinds of neurons: sensory and motor. **Sensory neurons** convey electro-chemical impulses from sensory organs in the periphery (such as the skin) to the spinal cord and the brain (called the **central nervous system,** or **CNS**). **Motor neurons** conduct impulses from the CNS to the periphery. Because the motor neurons carry electrical impulses from the CNS to the muscle cells, they signal the muscles to contract or to relax and, therefore, reg-

ulate muscular movement. The endings of the motor neuron connect, or synapse, with muscle cells in the periphery of the body. This motor neuron–muscle cell synapse is called the neuromuscular junction, or **motor end plate** (Figure 1.5). The basic functional unit of the neuromuscular system is the **motor unit,** which consists of one motor neuron and the muscle cells that it innervates. Motor units are arranged according to muscle fiber type. A neuron capable of conducting nervous impulses very rapidly synapses with the cells of fast-twitch muscle fibers. The cells of slow-twitch muscle fibers are controlled by somewhat slower-conducting neurons.

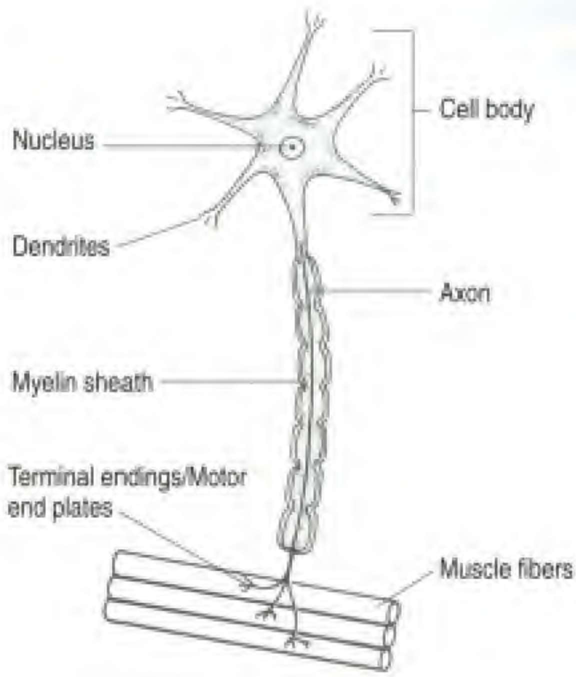


Figure 1.5
Basic anatomical structure of a motor neuron (or nerve cell) and motor end plate

Basic Organization of the Muscular System

The skeletal muscle is a complex tissue. Basically, muscle is surrounded by a layer of connective tissue called the **epimysium.** At the ends of a muscle, the epimysium thickens into a **tendon** that connects the muscle to the bone. Sublayers of connective tissue further divide each muscle into bundles of individual muscle cells, and, finally, each individual muscle fiber is covered by the **endomysium** (Figure 1.6).

An individual muscle cell is composed of many thread-like protein strands called

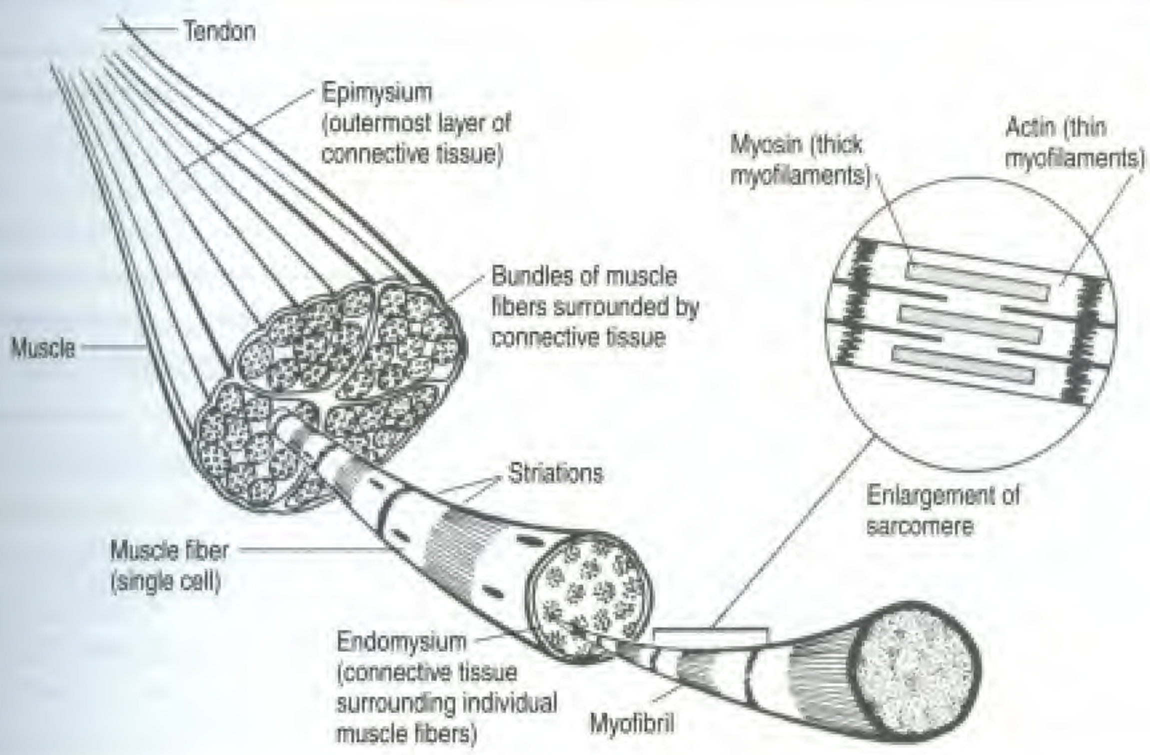


Figure 1.6
Organization of muscle

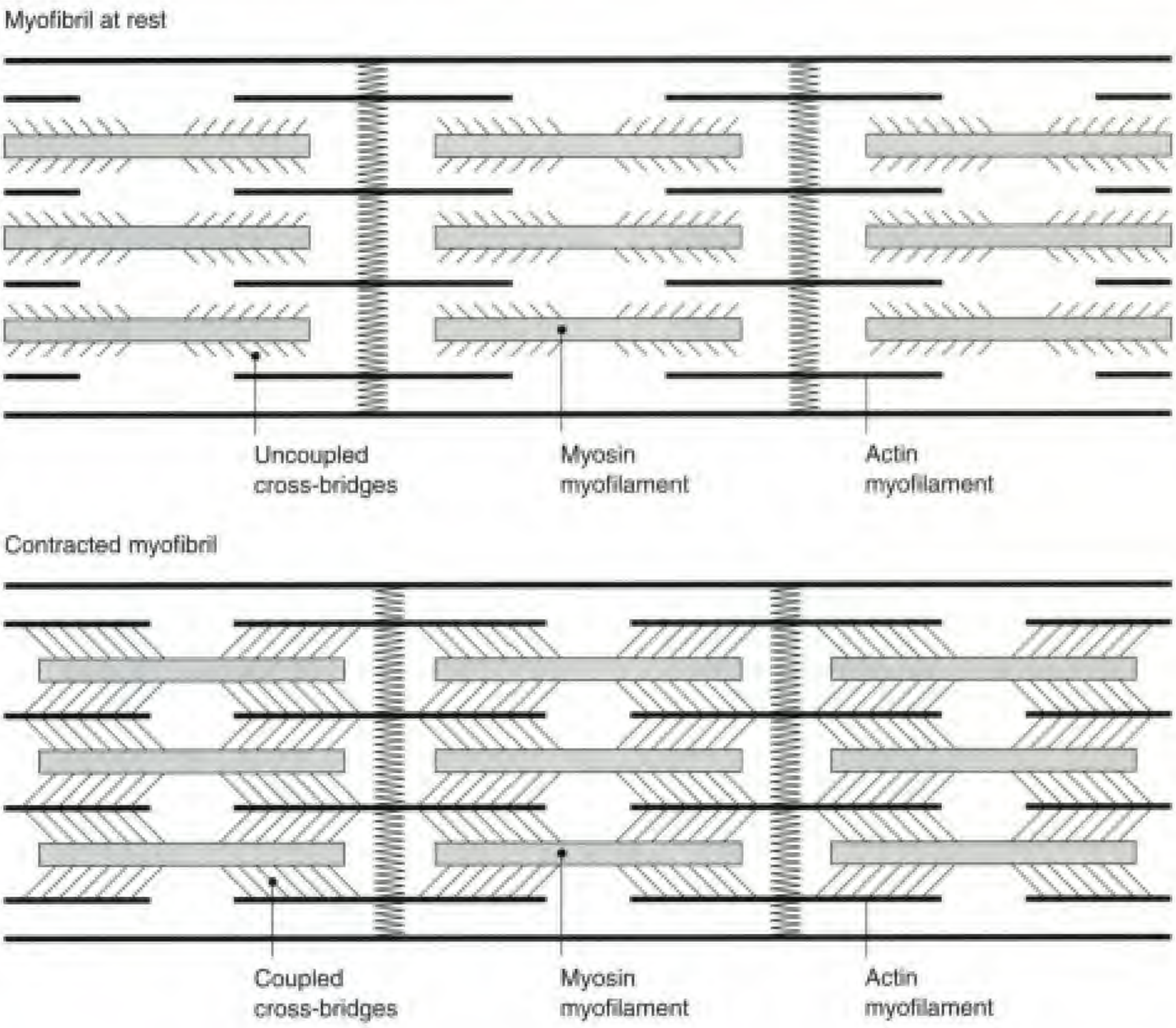
myofibrils that contain the **contractile proteins.** The basic functional unit of the myofibril is the **sarcomere.** Within the sarcomere are two protein **myofilaments:** the thick myofilament is **myosin,** and the thinner myofilament is **actin** (see Figure 1.6). The myosin and actin myofilaments are arranged to interdigitate in a prescribed, regular way, resulting in a pattern of alternating light and dark bands, or striations, within the sarcomere. Tiny projections called cross-bridges extend from the myosin myofilaments toward the actin myofilaments.

According to the **sliding filament theory,** muscular contraction occurs when the cross-bridges extending from the myosin myofilaments attach (or couple) to the actin myofilaments and pull them past the myosin myofilaments. As the cross-bridges produce tension, the muscle shortens. The actual muscle shortening occurs as the actin myofilaments are pulled toward the center of the sarcomere, and the sarcomere shortens (Figure 1.7). The coupling of myosin and actin and the shortening process are dependent upon the availability of ATP to link actin and myosin and to provide the energy to allow shortening to occur.

Types of Muscular Contraction

What is described above is a form of **isotonic** muscular contraction, in that there is joint movement when the muscle is stimulated. Tension (or force) develops throughout the muscle as it contracts, but the tension

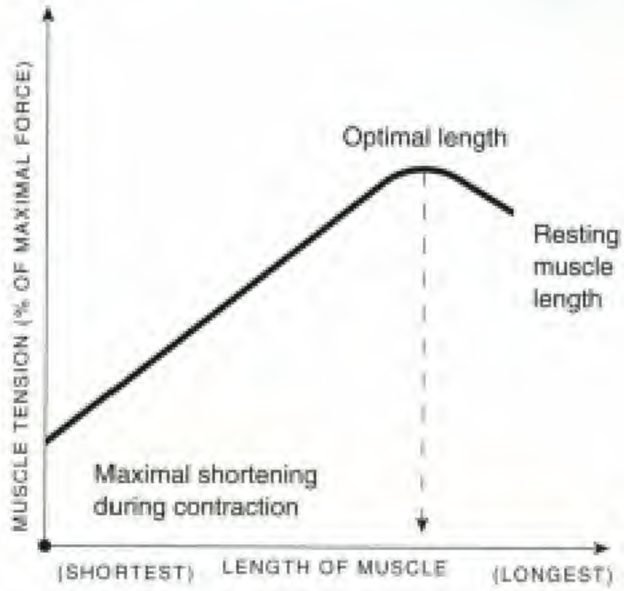
Figure 1.7
The sliding filament theory



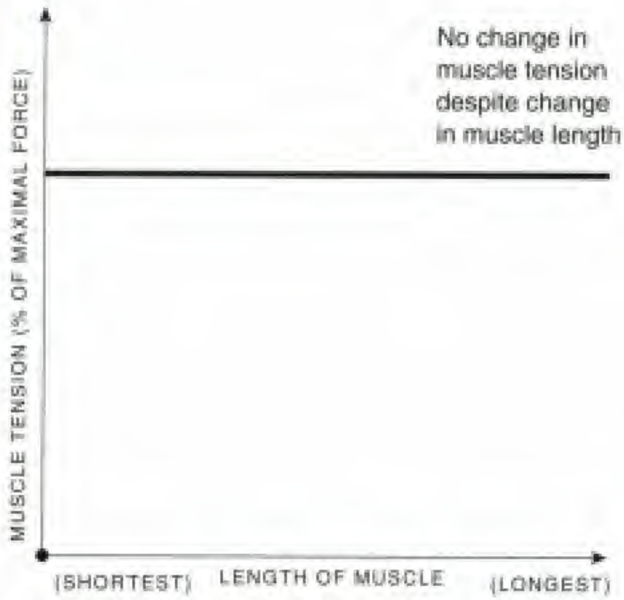
changes with the total length of the muscle and the angle of the joint. The greatest force is generated at the muscle's optimal length, where the actin and myosin myofilaments are aligned so that the largest number of cross-bridges between the myofilaments is activated simultaneously. At all other lengths, fewer cross-bridges are simultaneously coupled to actin myofilaments and, therefore, less force can be developed. The relationship of muscle tension (force) to muscle length during an isotonic contraction is illustrated in Figure 1.8a.

There are two types of isotonic contraction: **concentric** and **eccentric.** A concentric contraction occurs when the muscle shortens when it is stimulated. An eccentric contraction is the opposite of a concentric contraction in that the muscle develops tension as it lengthens against a resistance (rather than as it shortens against a resistance). This is sometimes called "negative work." Using walking up and down a flight of stairs as an example, going up the stairs requires the quadriceps muscle group to contract concentrically (shortening and lifting the weight of the body against gravity), while going down the stairs requires the quadriceps to contract eccentrically (slowly lengthening and lowering the weight of the body with gravity). In typical weight-lifting movements, eccentric contractions usually follow concentric contractions.

Isometric muscular contractions occur when actual muscle shortening does not take place. Since no joint movement occurs, this type of contraction is sometimes referred to as a static contraction. An example of an isometric muscle contraction is holding a weight at arm's length or attempting to move an immovable object (e.g., exerting force outward against a door frame). Isometric exercises are often used during physical rehabilitation and physical therapy when a joint has been injured. By contracting the muscles isometrically, an individual can maintain or increase muscular strength without aggravating the injured joint. It should be remembered, however, that because no joint movement is taking place, increases in strength are very specific to the joint angle at which the contractions are carried out



a. Isotonic contraction



b. Isokinetic contraction

Figure 1.8
The muscle length–tension curve during two forms of contraction

and that contractions should be carried out at several joint angles.

Isokinetic contractions, in outward appearance, look much like isotonic contractions. In an isotonic contraction, however, tension within the muscle changes throughout the range of motion. To accomplish an isokinetic contraction, special equipment is required to alter the resistance offered to the muscle as it contracts at a constant velocity. This approach is sometimes referred to as "accommodating-resistance" or "variable-resistance" exercise. Isokinetic exercise enables maximal tension to develop in a muscle throughout its entire range of motion (Figure 1.8b). With isotonic exercise, the maximal amount of weight that can be lifted corresponds to a weight that can be lifted through the weakest point in the range of motion. Thus, the muscle is only developing maximal tension at that point and tension development (as a percentage of maximal tension) varies throughout the range of motion.

Muscular Strength and Endurance

Resistance-training programs can be designed to improve either muscular strength or muscular endurance. While there is considerable overlap in the training responses, there are several key differences. The sections below discuss how the principle of **specificity** applies to these two components of physical fitness.

Muscular Strength

Strength refers to the maximal tension or force produced by a muscle or muscle group. Strength is usually measured by determining how much weight can be lifted in a single effort. The one-repetition maximum (1-RM) test is determined through a trial-and-error procedure using either free weights (barbells and weights) or special machines (e.g., dynamometers, selectorized equipment, multi-station gym). Most often, 1-RM tests are completed for the following muscle groups: (a) the bench press for the muscles of the chest and upper arms; (b) the arm curl for the muscles on the anterior aspect of the upper arms; and (c) the leg press or squat for the muscles of the upper legs and hips.

Programs designed specifically to develop muscular strength should use a high-intensity (80 to 90% of 1 RM), low-repetition format (fewer than eight repetitions), and the movements should be performed carefully at a controlled speed so there is a consistent application of force throughout the movement. Good posture and body mechanics are extremely important to avoid injury, as is breathing properly and avoiding the **Valsalva maneuver,** which occurs when the breath is held while a great deal of force is exerted. When the breath is held, the glottis in the back of the throat is closed. Exerting force with the glottis closed results in an increase in pressure within the chest cavity (intrathoracic pressure). This increase in pressure squeezes down on the large veins in the chest cavity, impeding venous return (blood flow back to the heart). If blood flow back to the heart is impeded, the heart has less blood to pump out. As a consequence, there is less flow of blood and oxygen to the brain, and dizziness and fainting may occur. It is generally recommended that people exhale when they are performing the concentric phase of a lift and inhale during the eccentric phase.

Movements requiring a high level of strength recruit both ST and FT muscle fibers. Because little total work is done, strength-training movements do not require or develop a high level of aerobic capacity because the muscles are using primarily the phosphagen (ATP-CP) system. And, because strength

training is relatively stressful on the connective tissues and muscular structures of the body, it is usually recommended that heavy strength training be performed only two or three times per week. It is important that the muscles and supporting structures be given time to recover sufficiently between workouts. At the same time, strength training can help support bone health during aging.

Muscular **hypertrophy** is often associated with a strength-development program. This hypertrophy is the result of an increase in the size of individual muscle cells. The increase in size is due to a proliferation of actin and myosin myofilaments within the myofibrils, especially within the fast-twitch muscle fibers. One common misconception is that women will develop "large" muscles if they strength-train. Generally, women do not experience muscular hypertrophy to the same extent as men, because the male hormone testosterone is important in synthesizing the contractile proteins. Nevertheless, women will increase substantially in strength in response to a progressive strength-training program.

Consistent with the **reversibility principle,** training adaptations will gradually decline if not reinforced by a maintenance program. With muscle disuse, as in paralysis, muscle **atrophy,** or wasting, occurs. Strength training even once per week appears to be sufficient to maintain strength gains and muscle size.

Muscular Endurance

Endurance refers to the ability to repeatedly contract a muscle or muscle group against resistance. Tests of muscular endurance usually involve selecting a fixed percentage of the maximum strength (e.g., 70% of the 1 RM) and counting the number of repetitions that can be completed without resting. Sit-up or pull-up tests are other examples of muscular-endurance tests (not of strength tests, as is often thought).

It is usually recommended that muscular-endurance training be conducted using a moderate-resistance (40 to 70% of 1 RM), high-repetition (10 to 50 repetitions) format. Because this type of format is not as stressful to the muscles and connective tissue, muscular-endurance training can be completed as often as three to five times per week for maximum results. If training for a particular sport, the speed of contraction should be matched to the rate required during performance.

Training for muscular endurance is specific to both ST and FT muscle fibers and motor units. Training increases the concentration of oxidative enzymes that extract oxygen from the blood in both types of fibers, thus making energy production more efficient. An increase in tissue **vascularity,** or an increase in the number and size of blood vessels, often accompanies this type of program. Increased vascularity enhances blood supply and, consequently, oxygen delivery to the myofibrils. It also aids in transporting metabolites, such as lactate, away from the contracting muscle.

Flexibility

Flexibility refers to the range of motion (ROM) possible about a joint. Flexibility is often related to age: Young children are usually extremely flexible, while the elderly gradually lose much of the flexibility they had as younger adults. With specific flexibility training, the muscles and connective tissues adapt by elongating, thus increasing the range of motion.

ROM can be limited by the bony structure of a joint, the ligamentous structure of a joint, or the musculotendinous structure of the muscle(s) spanning the joint. The bony structure of a joint is a self-limiting factor

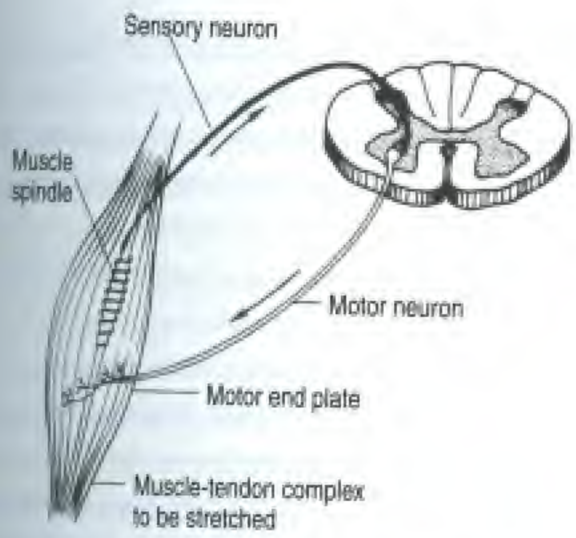
that cannot be altered. A joint ligament (the fibrous band connecting bones) or joint capsule should not be stretched, because doing so leads to an unstable joint (joint laxity) and an increased risk of joint injury. Therefore, the only desirable way to alter that range of motion is by gently stretching the musculotendinous structures controlling the movement of the joint. These structures can sometimes become extremely taut, causing a reduction in the normal range of motion.

Flexibility may be related to the incidence of acute muscle injury due to strenuous exercise and also to **delayed onset muscle soreness (DOMS).** Acute muscle injuries such as muscle pulls or tears are more likely to occur if the muscle fibers or surrounding tissues are so taut and inflexible that a sudden stretch causes tissue injury. The exact cause of DOMS, which occurs 24 to 48 hours after strenuous exercise, is not known. Evidence suggests that it is caused by microscopic damage to muscle cell ultrastructure due to excessive mechanical force exerted by the muscle and connective tissues. DOMS is particularly associated with the eccentric phase of a movement, especially if the person is unaccustomed to the exercise. Stretching exercises performed before and after an exercise session may help to prevent soreness, and also to relieve soreness when it does occur, but not all of the evidence suggests this.

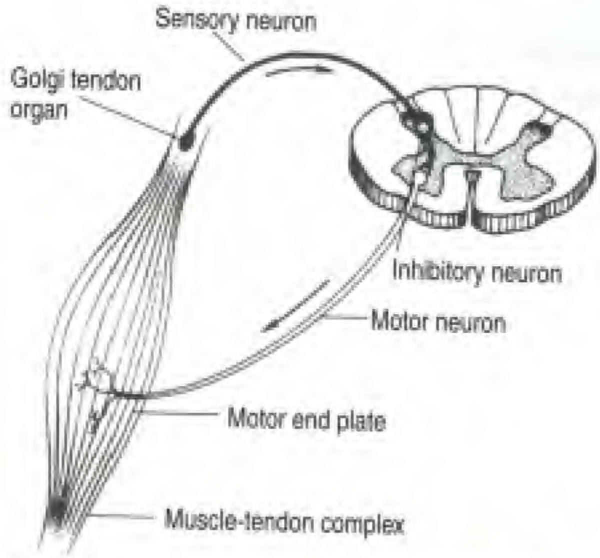
There are three types of stretching to increase flexibility: static stretching; dynamic, or ballistic, stretching; and proprioceptive neuromuscular facilitation. **Static stretching** involves holding a static (nonmoving) position so that a joint is immobilized in a position that places the desired muscles and connective tissues passively at their greatest possible length. A static stretch position should be held for 15 to 30 seconds to achieve optimal results (Bandy & Irion, 1994; McHugh et al., 1992). Static stretching is best characterized as low-force, long-duration stretching and has repeatedly been shown to produce good results with little muscle soreness. In fact, static stretching is commonly used to reduce muscle soreness. Little risk of physical injury exists if static stretching is performed correctly. However, static stretching performed just before exercise has been shown to transiently reduce muscle strength.

Dynamic, or ballistic, stretching is characterized by rhythmic bobbing or bouncing motions representing relatively high-force, short-duration movements. **Ballistic stretching** motions, while seemingly effective, actually invoke stretch reflexes that oppose the desired stretching. Muscle stretch reflexes are involuntary motor responses controlled by the **muscle spindle,** a sensory organ located within the muscle. When a muscle spindle is stimulated, an impulse is propagated over a sensory nerve fiber. The nerve fiber synapses in the spinal cord with a motor neuron that returns to the muscle containing the muscle spindle (Figure 1.9a). This reflex causes the suddenly stretched muscle to respond with a corresponding contraction; the amount and rate of this contraction varies directly with the amount and rate of the movement causing the initial stretch. Thus, ballistic stretching evokes the opposite physiological response from the one desired—an increase in muscle tension.

A firm static stretch, on the other hand, invokes an inhibition of the stretch reflex by stimulating another sensory organ (with a higher threshold level) called the **Golgi tendon organ.** When stimulated, this organ causes an inhibition not only of the muscle in which the muscle spindle was stretched, but also of the entire muscle group (Figure 1.9b).



a. Simple muscle stretch-reflex arc: The stretch of the muscle spindle causes a reflex contraction.



b. Simple inverse stretch-reflex arc: The stretch of the Golgi tendon organ causes a reflex inhibition (relaxation).

Figure 1.9
Simple muscle reflexes

Thus, static stretching brings about a reduction in muscle tension—the desirable physiological response. In addition, static stretching is safer than ballistic stretching because it does not impose a sudden, possibly injurious force upon the tissues.

A third type of stretching, **proprioceptive neuromuscular facilitation,** or **PNF,** is a technique originally developed for rehabilitative purposes in physical therapy. PNF involves statically stretching a muscle immediately after maximally contracting it against resistance. Carefully controlled experiments using PNF have generally found it to be superior to either static or **dynamic stretching.** However, it is not practical in the majority of cases, as it requires a partner trained in the technique.

General flexibility exercises should be part of every physical-fitness program and should be included primarily during the cool-down phase of every exercise session. Some general principles specific to the enhancement of flexibility include the following:

- A low-level aerobic warm-up (such as walking and swinging the arms) should precede specific stretching exercises to increase blood flow.
- Stretching exercises should be performed without bouncing or jerking, which may injure connective tissues and stimulate the stretch reflex.
- Never attempt to stretch a muscle or muscle group beyond its normal range of motion.
- All stretching should be done gently and only to the extent that muscle tension is perceived; stretching should not be painful.
- Instructors should understand that their participants will vary greatly in their flexibility. Everyone is not equally flexible or equally responsive to flexibility training.

The Cardiovascular–Respiratory Systems

Cardiorespiratory endurance is defined as the capacity of the heart and lung systems to deliver blood and, hence, oxygen to the working muscles during sustained exercise. Oxygen is used to produce ATP to perform low- to moderate-intensity exercise for long periods. The capacity to perform aerobic exercise depends largely on the interaction of the

cardiovascular system and the respiratory system to provide oxygen to the active cells so that carbohydrates and fatty acids can be converted to ATP for muscular contraction. These two systems also are important for the removal of metabolic waste products such as carbon dioxide and lactate, and for the dissipation of the internal heat produced by metabolic processes.

There are three basic processes that must interact to provide adequate blood and nutrients to the tissues:

1. Getting oxygen into the blood—a function of **pulmonary ventilation** coupled with the oxygen-carrying capacity of the blood
2. Delivering oxygen to the active tissues—a function of cardiac output
3. Extracting oxygen from the blood to complete the metabolic production of ATP—a function of localizing the delivery of cardiac output to the active muscles and the oxidative enzymes located within the active cells

See Chapter 2 for information on basic cardiovascular and pulmonary anatomy.

Oxygen-carrying Capacity

The oxygen-carrying capacity of blood is determined primarily by two variables: the ability to ① ventilate the lungs adequately and ② the hemoglobin content of the blood. Pulmonary **ventilation** is a function of both the rate and depth (**tidal volume**) of breathing. With the beginning of exercise, both tidal volume and breathing rate increase. This increase in ventilation volume brings more oxygen into the lungs, where it can be absorbed into the blood. In normal individuals, respiration does not limit exercise performance. However, individuals with **emphysema** (degradation of the alveoli) or **asthma** (constriction of the breathing passages) cannot move enough air through their lungs to adequately oxygenate the blood. As a result, the blood leaving the lungs is not sufficiently loaded with oxygen, and exercise capacity is diminished.

Hemoglobin (Hb) is a protein in red blood cells that is specifically adapted to bond (carry) oxygen molecules. When oxygen enters the lungs, it diffuses through the pulmonary membranes into the bloodstream, where it binds to hemoglobin. The oxygen is then carried within the bloodstream throughout the body. Persons with low hemoglobin concentrations cannot carry as much oxygen in their blood as persons with high hemoglobin concentrations. For instance, in individuals with **anemia** (less than 12 g of Hb per 100 mL of blood), the blood's oxygen-carrying capacity is severely limited, and they fatigue very easily. In most healthy persons, however, the oxygen-carrying capacity of the blood is not a limiting factor in the performance of aerobic exercise.

Oxygen Delivery

Probably the most important factor in cardiorespiratory endurance is the delivery of blood to the active cells, which is a function of **cardiac output.** Cardiac output is the product of **heart rate** (**HR;** beats per minute) and **stroke volume** (**SV;** the quantity of blood pumped per heart beat):

$$\text{Cardiac output} = \text{HR} \times \text{SV}$$

At rest, cardiac output averages about 5 liters (1.5 gallons) per minute. During maximal exercise, this number can increase to up to 30 to 40 liters (10 gallons) per minute in highly trained individuals. The increase in cardiac output is brought about by an increase in both HR and SV. HR generally

increases in a linear fashion up to maximal levels, while SV increases up to approximately 40 to 50% of an individual's maximal capacity and then plateaus. The increase in SV is brought about by increases in both venous return and in the contractile force of the heart.

Also during exercise, blood flow patterns change according to metabolic need. Blood is shunted to the working muscles (to produce ATP for contraction) and to the skin (to dissipate the metabolic heat produced), while the amount of blood flowing to less active organs such as the kidneys and intestinal tract decreases.

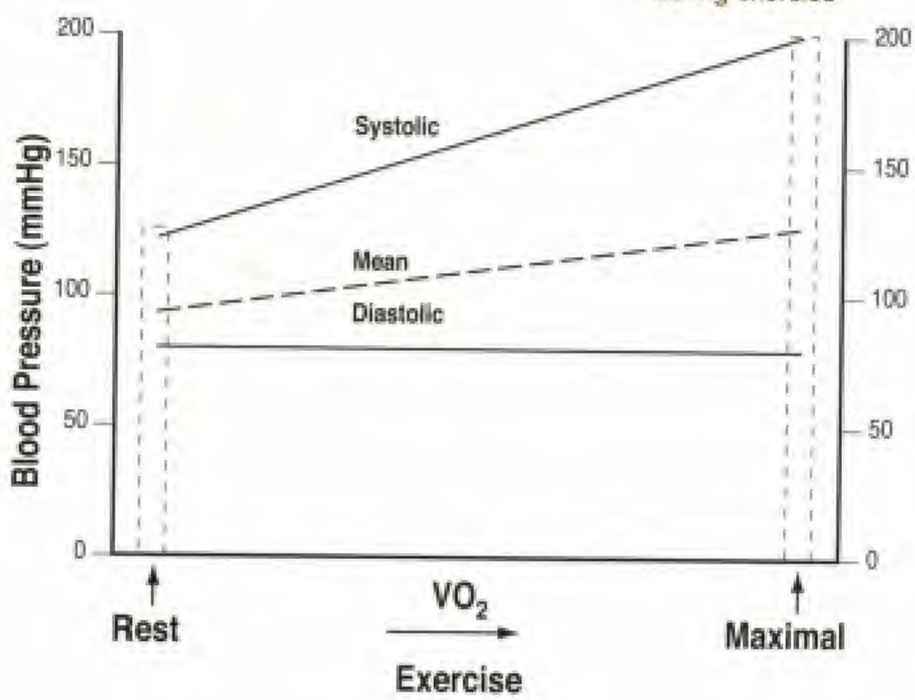
Blood pressure is also very important in blood-flow distribution because it provides the driving force that pushes blood through the circulatory system. Blood pressure is influenced by many factors. **Systolic blood pressure** is a function of the force generated by the heart during its contraction phase (systole) and the resistance offered by the vessels to the blood flowing through them (peripheral resistance). Just as the strength of heart contractions can vary, some blood vessels (notably the smaller arteries called arterioles) can contract (**vasoconstriction**) or relax (**vasodilation**) and thus alter their resistance to blood flow, a fact important in determining the pattern of blood flow. During exercise, vasoconstriction occurs in the vessels of inactive organs (such as the intestine), and vasodilation occurs in vessels of active organs (muscles), thus redirecting blood flow to areas of the body where it is most needed. Similar to HR, systolic blood pressure increases in a linear fashion throughout the range of exercise intensities (Figure 1.10).

Diastolic blood pressure is a measure of the pressure in the arteries during the relaxation phase (diastole) of the heart cycle. Because of the vasodilation of the blood vessels within the working muscles, more blood is allowed to enter the muscles. As a result, less blood is "trapped" on the arterial side of the circulation. Diastolic blood pressure usually stays the same or decreases slightly during exercise (see Figure 1.10).

Oxygen Extraction

A third factor important in cardiorespiratory endurance is the extraction of oxygen from the blood at the cellular level for the aerobic production of ATP. The amount of oxygen extracted is largely a function of muscle fiber type and the availability of specialized oxidative enzymes. The slow-twitch muscle fibers are specifically adapted for oxygen extraction and utilization due to their high levels of oxidative enzymes. One of the most important adaptations to training is an increase in the number and size of the mitochondria, with a corresponding increase in the levels of oxidative enzymes used to aerobically produce ATP.

Figure 1.10
Normal responses to blood pressure during exercise



Acute Responses to Aerobic Exercise

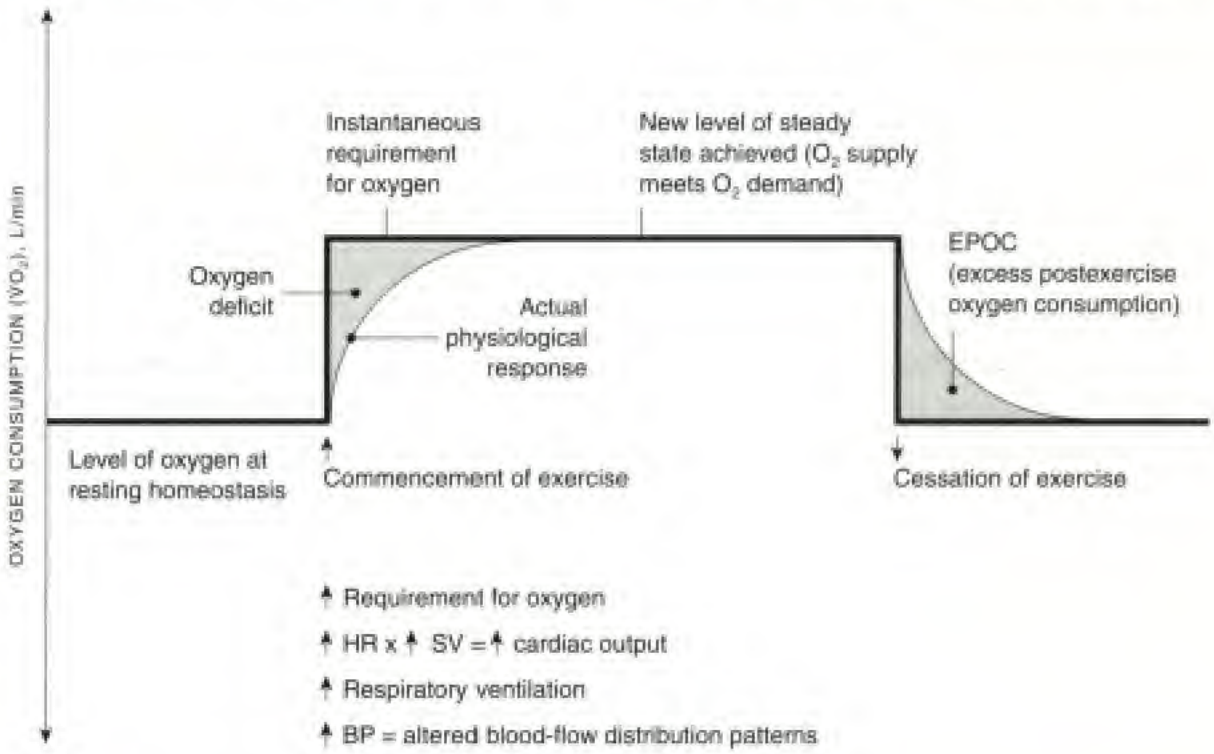
Aerobic exercise is best characterized as large-muscle, rhythmic activities (e.g., walking, jogging, aerobic dance, swimming, cross-country skiing) that can be sustained without undue fatigue for at least 10 to 15 minutes. Such movement patterns depend on the oxidative metabolic pathways to create ATP, and the goal of the body is to be in a **steady state,** where the energy needs are being met aerobically. The other metabolic pathways (the phosphagen system and anaerobic glycolysis) are used only minimally to produce energy at the onset of these types of activity.

Figure 1.11 highlights the changes that take place. When aerobic exercise begins, the body rapidly responds to increase the quantity of oxygen available to produce the ATP necessary to meet the molecular demands. Cardiac output increases to deliver more blood to the active muscle cells. To meet this requirement, HR, SV, and systolic blood pressure increase immediately. Pulmonary ventilation also increases to provide more oxygen to the red blood cells in the lungs.

The bold line in Figure 1.11 indicates the level of **oxygen consumption** required at rest and the instantaneous increase that occurs with commencement of exercise (at upward arrow). The line returns to the resting level when exercise is abruptly stopped (at downward arrow). The actual oxygen consumption that results from the physiological responses to aerobic exercise is indicated by the sloping line in the figure. Notice that actual oxygen consumption does not immediately meet the physiological requirement for oxygen. Instead, an **oxygen deficit** occurs.

The physiological responses that occur with commencement of exercise take approximately two to four minutes to meet the increased metabolic demands for oxygen. During this time, the anaerobic metabolic systems—which are capable of producing ener-

Figure 1.11
Oxygen consumption during aerobic exercise



Note: HR = Heart rate; SV = Stroke volume; BP = Blood pressure

gy more rapidly—produce the energy needed to carry out the exercise. During this period, the phosphagens are depleted, and excess lactate is produced. When the cardiorespiratory systems have fully responded, a new level of oxygen consumption is achieved. If the exercise intensity is not too high relative to the body's ability to provide oxygen to the muscles, a steady state is achieved.

With cessation of exercise, the requirement for oxygen abruptly returns to the initial resting level. Again, however, the body responds more slowly. As cardiac output, blood pressure, and **respiratory ventilation** return to resting levels, oxygen consumption slowly declines as well, but is still elevated above resting levels. This is called **excess post-exercise oxygen consumption (EPOC).** The energy produced during this time is used to replenish the depleted phosphagens, to eliminate accumulated lactate if it has not already been cleared from the blood, and to restore other homeostatic conditions.

If exercise intensity is so high that the body cannot meet all of the metabolic demands of the muscles aerobically (i.e., not reach a steady state), the muscles have to supplement ATP production via anaerobic metabolism. When this occurs, one is said to have exceeded the **anaerobic threshold (AT).** When someone exceeds their AT, lactate accumulates very rapidly in the blood, the oxygen deficit and corresponding EPOC are extremely high, and exercise cannot be performed for more than a few minutes (Figure 1.12). It is also at this point that hyperventilation begins to occur. As the body tries to buffer the lactate (remove it from the system), one of the by-products is carbon dioxide (CO_2). Carbon dioxide provides a powerful stimulus to the respiratory system, and the body increases respiration in an attempt to "blow off" the excess CO_2. This increase in respiration is often called the ventilatory threshold (VT) and is often used as an indirect indicator of the AT.

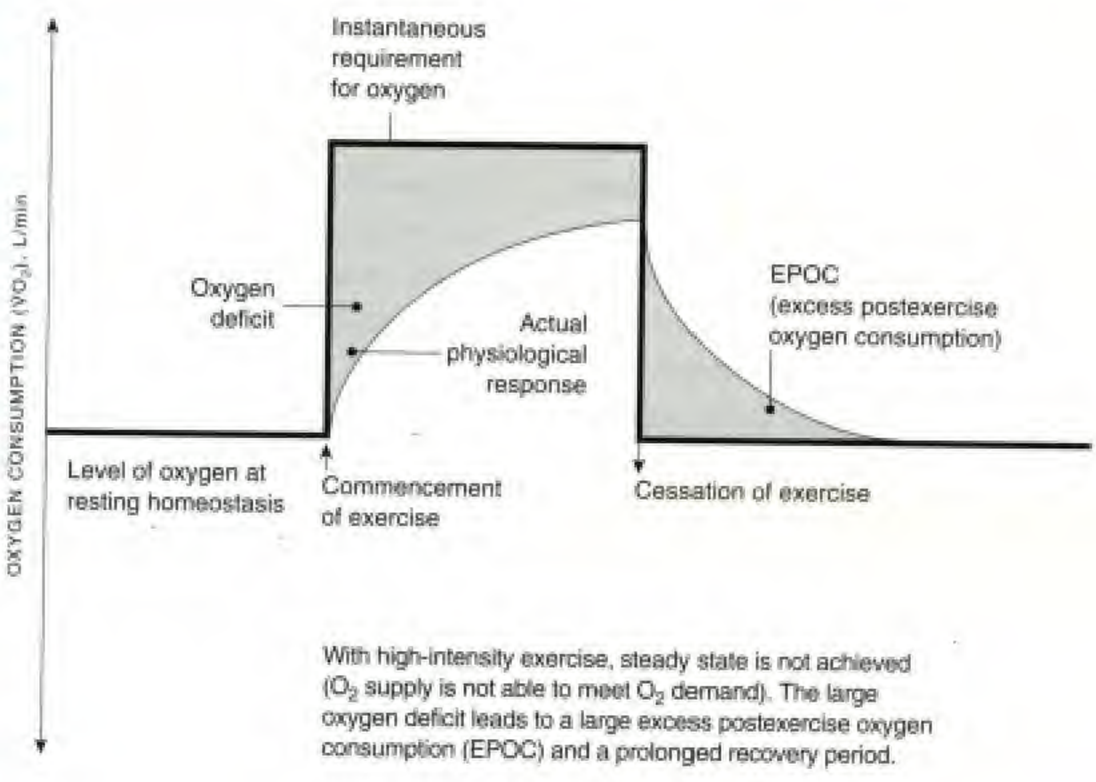


Figure 1.12
Oxygen consumption during anaerobic exercise

Guidelines for Improving Cardiovascular–Respiratory Endurance

When developing an exercise program, it is important to individualize it for each participant. There are four basic variables to consider when developing an exercise program to improve cardiovascular-respiratory endurance:

1. Exercise **intensity**—how hard to exercise
2. Exercise **duration**—how long to exercise
3. Exercise **frequency**—how often to exercise
4. Exercise **mode**—what type of exercise

The following general recommendations are based upon well-established guidelines from the American College of Sports Medicine.

Intensity of Exercise

The principles of aerobic and anaerobic energy production make it clear that to improve cardiorespiratory endurance, the exercise needs to be conducted within an aerobic-training zone. Exercise at too great an intensity for a client's level of fitness will rely on the anaerobic systems, not the aerobic systems. Research shows that an acceptable exercise intensity for fitness improvement is in the range of about 40 to 85% of heart-rate reserve, which corresponds to approximately 60 to 95% of maximum heart rate. The ranges are broad because genetic factors, as well as initial fitness level, influence the degree of improvement. The higher a client's initial level of fitness, the higher the appropriate exercise intensity. Research also shows that very deconditioned individuals may improve aerobic fitness at intensities below the minimal intensities listed above.

Duration of Exercise

The recommended time that an individual should exercise aerobically ranges from 20 to 60 minutes. In general, the lower the intensity, the longer the duration needs to be. Individuals training at a low intensity should exercise for at least 30 minutes, while 20 to 30 minutes may be sufficient for individuals who are training at higher intensities. While it was previously thought that activity must be sustained for the minimum time to cause adequate aerobic **overload,** subsequent research has shown that three 10-minute sessions will lead to the same improvements as one 30-minute session if they are done at the same relative intensity (Franklin, 1999; Murphy & Hardman, 1998; Jakicic et al., 1995).

Because aerobic training is related to the oxygen cost of activity, there is an inverse relationship between intensity and duration. If intensity is increased, the duration can be decreased and a similar training effect will be achieved. Conversely, if the intensity is decreased, the duration must be increased to elicit the same training effect. In general terms, when the cells of the body consume 1 liter (about 1 quart) of oxygen per minute, about 5 kilocalories per minute have been expended (1 liter O_2/min $\cong$ 5 kcal/min). If 2 liters per minute are consumed, the expenditure would be about 10 kilocalories per minute. For example, walking costs approximately 5 kcal/min and jogging costs approximately 10 kcal/min. So jogging for 30 minutes would use about 300 kilocalories (10 x 30 = 300), which is the same as 60 minutes of walking (5 x 60 = 300). Therefore, walking for twice as long as jogging will result in approximately the same training effect. This is an especially important consideration for the deconditioned client.

Frequency of Exercise

The proper type of activity, done at the correct intensity and continued for a sufficient

length of time, must be performed at least three days per week. While training three days per week may be sufficient, especially for those just beginning an exercise program, more frequent exercise, such as a brisk daily walk, is certainly acceptable. It also will lead to more rapid improvements. Keep in mind that it is important to allow for adequate rest and recovery to minimize the risks associated with training. Most experts encourage even competitive athletes to take at least one day per week for rest or a low-intensity recreational activity, such as a round of golf.

Interval training involves exercising at high intensity levels (80 to 100% of maximal HR) for relatively brief periods (usually 10 seconds to five minutes) with intervening rest or relief periods (walking, jogging) that allow HR to decline. The exercise periods often are "anaerobic" rather than "aerobic." For athletes in training, interval training may offer an advantage, because the higher intensity may more accurately simulate competitive conditions and result in improved performance. An athlete can thus maintain a faster pace before going into anaerobic metabolism. Generally, however, continuous exercise at lower levels of intensity is safer and more compatible with the goals of most individuals. Lower-intensity continuous training is less stressful to the musculoskeletal system and, therefore, more appropriate for middle-aged and older adults.

Mode of Exercise

To induce changes in aerobic capacity, it is recommended that the activity involve large muscle groups and be rhythmic in nature. Most traditional locomotive-type activities are considered to be good aerobic exercises (e.g., walking, running, cross-country skiing, swimming, rowing, cycling, stepping) because they utilize the large muscles of the body and can be continued for prolonged periods. There is very little difference in the degree of aerobic improvement between various exercise modes, as long as they are conducted at the same relative intensity. Exercises that simultaneously utilize the upper and lower body (e.g., cross-country skiing, combined upper- and lower-body cycle ergometry) may have an added benefit, as they increase total-body muscular endurance and allow the work to be shared by both the upper and lower body, thus minimizing local muscular fatigue. This may allow more total work to be completed in a workout, resulting in greater total caloric expenditure.

It should be noted that the recommendations concerning intensity, frequency, duration, and mode of exercise relate specifically to improving aerobic capacity and are distinctly different than the recommendation by the Surgeon General that adults accumulate at least 30 minutes of moderate-intensity physical activity on most, if not all, days of the week. This "physical activity" can include everyday activities (e.g., gardening, mowing the lawn). Doing so will improve the overall health and well-being of the general population. If the guidelines provided by the American College of Sports Medicine are adhered to, the Surgeon General's recommendations also will be met.

Warm-up and Cool-down

The period of exercise at the desired target heart rate should be preceded by a warm-up of about five to 10 minutes. The warm-up should include limbering exercises to prepare the musculoskeletal system for the exercises to be performed. Static stretching—holding a steady stretch with the desired muscles at their greatest possible length—is beneficial to joints and

muscles and may help to prevent injuries and muscle soreness. Warm-up activities should also include large-muscle movements to gradually increase HR, blood pressure, cardiac output, and respiratory ventilation to intermediate levels so that these mechanisms are not suddenly taxed. A proper warm-up may also reduce the incidence of exercise-induced cardiac abnormalities such as **arrhythmias** (abnormal heart rhythms) or **ischemia** (lack of blood flow to the heart muscle).

It is important to cool down gradually after a period of vigorous exercise. Abruptly stopping exercise after a vigorous workout may allow a large quantity of blood to pool in the lower extremities, reducing venous return. As a result, cardiac output is reduced and blood flow to the brain is diminished, which may cause dizziness or faintness. It is best to provide a series of movements during the cool-down period that allows the muscles and cardiorespiratory system to gradually return to their pre-exercise levels. A gradual cool-down also aids in the removal of accumulated **lactic acid** and may prevent cardiac arrhythmias following strenuous exercise. When heart rates are near resting levels, muscle stretching and limbering exercises should again be performed to reduce the risk of developing DOMS. Probably the most effective time to perform flexibility exercises is when muscles are warm and body temperature is elevated after exercise.

Use of Hand or Ankle Weights With Aerobic Exercise

Individuals often seek ways to increase the intensity of an aerobic workout. Adding extra weight in the form of hand, wrist, or ankle weights increases the total mass that must be moved, so it seems logical that using extra weight would be beneficial in boosting the physiological demands of an activity. Research on the use of hand or wrist weights during a variety of different aerobic activities (e.g., walking, traditional aerobics, step aerobics) is very consistent and indicates that the use of 1- to 3-pound (450 to 1350 g) weights can increase heart rate by five to 10 beats per minute and oxygen consumption (as well as caloric expenditure) by about 5 to 15% compared to performing the same activity without weights. Weights greater than 3 pounds (1350 g) are not generally recommended, because they may put undue stress on the arm and shoulder muscles. Additionally, wrist weights are preferred over hand weights because they don't have to be gripped, which can cause an elevated blood-pressure response in some people.

The beneficial effect of ankle weights is lower than that of either hand or wrist weights. Weights ranging from 1 to 3 pounds (450 to 1350 g) can increase HR by an average of three to five beats per minute and oxygen consumption by 5 to 10% over unweighted conditions. A potential drawback to the use of ankle weights is that they may alter the biomechanics of the lower limbs, leading to injury. As a consequence, ankle weights are not generally recommended for use during aerobic exercise activities.

Long-term Adaptations to Aerobic Exercise for Healthy Participants

When performed appropriately, a regular program of aerobic exercise can have significant physiological benefits in as little as eight to 12 weeks. Changes to the cardiorespiratory system include improvements in cardiac efficiency (increased SV and a lower HR),

increased respiratory capacity, and, ultimately, an increase in maximal oxygen consumption ($\dot{V}O_2max$). These improvements provide individuals with a greater physiological reserve and allow them to perform everyday activities with less stress and strain. Regular exercise has also been shown to result in lowered blood pressure in moderately hypertensive individuals. This results in less work for the heart muscle and puts less stress on the blood vessels.

The benefits of aerobic exercise are not limited to the cardiovascular and respiratory systems. Studies have shown that weightbearing exercise promotes improved bone density, an extremely important consideration in the prevention of osteoporosis after age 50 to 60, particularly in women. Improvements in the control of blood glucose and blood lipids (e.g., cholesterol, triglycerides) are also associated with consistent physical activity. One of the main reasons many people exercise is to control body weight. Exercise obviously burns calories, but, just as importantly, exercise serves to maintain or increase lean body mass, which is vital for maintaining resting metabolic rate. It is the decrease in muscle mass that contributes to the fall in metabolic rate as people age. Finally, the psychological benefits of exercise cannot be overlooked. Exercise has long been associated with lower levels of anxiety and depression and a higher quality of life.

Long-term Adaptations to Aerobic Exercise for Persons With Chronic Disease

A well-planned aerobic-exercise program also can provide significant health benefits to persons with chronic diseases such as diabetes, osteoarthritis, obesity, pulmonary disease, and coronary heart disease.

Individuals with type 2 diabetes have difficulty utilizing glucose (carbohydrates) for energy, due to either a lack of insulin or the body's inability to utilize the available insulin (insulin resistance). Most of the time, individuals with type 2 diabetes are overweight. Treatment of type 2 diabetes usually involves a three-pronged approach: diet, weight loss, and exercise. Exercise enables carbohydrates to be used more effectively by promoting glucose uptake from the blood, thereby reducing insulin resistance. Exercise also helps to promote weight loss. Exercise programming for persons with type 2 diabetes is rarely dangerous or difficult. Exercise for individuals with type 1 diabetes is much more complex and is beyond the scope of this book. Any program of exercise for individuals with type 1 diabetes must be performed under the guidance of a physician. The person with type 1 diabetes needs to understand the interactions between exercise, glucose uptake, insulin, and carbohydrate consumption, because exercise can result in **hypoglycemia,** or hazardously low blood sugar, if done inappropriately.

Osteoarthritis is a gradual, progressive degeneration of joint structures that makes even normal movements painful. It has been speculated that high-impact exercise early in life contributes to the incidence of arthritis later on. However, research has found no association between exercise intensity and the incidence of arthritis, other than the tendency for arthritic pain to occur in areas of the body that have experienced earlier athletic injury. In fact, lifelong exercisers have been found to have less osteoarthritis than nonexercisers. Maintenance of good flexibility and the development of moderate levels of muscular strength have been found to stabilize the

joints and provide relief for the minor aches and pains of arthritis. An exercise program for individuals with arthritis should focus on nonweightbearing exercise modalities (e.g., stationary cycling, water-based exercise) and should avoid high-impact stress on the knees, hips, and lower back.

Obesity (the condition of having excess body fat) has become a major health-related problem in the industrialized world. Excess body weight is associated with a number of chronic diseases, including **hypertension,** diabetes, and coronary artery disease. The most effective way to lose body weight and body fat is through a sound program of caloric restriction and low- to moderate-intensity aerobic exercise. Dieting alone is not effective. While severe dieting can lead to weight loss, the loss is frequently from the lean body mass (mainly the muscles) rather than from the fat mass of the body, which results in a decrease in metabolic rate. An exercise program for the obese or overweight client should focus on burning the maximum number of calories per session and avoiding musculoskeletal injuries. The goal should be to perform longer-duration (building up to 45 to 60 minutes per day), low- to moderate-intensity (40 to 60% of **heart-rate reserve**) exercise five to six days per week. Nonweightbearing or low-impact activities should also be stressed (e.g., walking, stationary cycling, aquatic exercise).

People with pulmonary disease are severely limited by the amount of air they can move into and out of their lungs. The blood does not get adequately oxygenated and exercise capacity is very low. The most common forms of pulmonary disease are emphysema, bronchitis, and asthma. Emphysema and chronic bronchitis are usually the result of long-term cigarette smoking, whereas the exact cause of asthma is unknown. Asthma occurs when the bronchi (large breathing passages) become constricted (bronchospasm), and the onset of symptoms is usually related to irritants such as tobacco smoke, animal dander, and cold air. Some people also experience exercise-induced asthma (EIA). The most widely accepted hypothesis for the cause of EIA is that airway cooling irritates the lining of the respiratory tree and causes the bronchospasm. It was once thought that individuals with pulmonary disease should not exercise. However, a regular program of aerobic exercise has been proven to decrease the amount of dyspnea (shortness of breath) in individuals with emphysema and bronchitis and increase their quality of life. People with asthma should also be encouraged to exercise and to have bronchodilator medications readily available if symptoms become severe. All patients with pulmonary disease should be under the care of a physician.

Coronary heart disease (CHD) involves partial or total closure of the coronary arteries, which results in symptoms or signs of ischemia (lack of blood flow to the heart muscle). The American Heart Association has identified a number of factors that increase the risk of **cardiovascular disease.** The primary **risk factors** are hypertension (elevated blood pressure), cigarette smoking, elevated blood lipid levels, and physical inactivity. Secondary risk factors include family history of heart disease, obesity, diabetes, being male, age over 65 for women and over 55 for men, and a high level of emotional stress. Obviously, little can be done to change one's age, gender, or family health history, but lifestyle changes can significantly alter the other risk factors. Regular participation in a well-planned aerobic exercise program has been shown to reduce high blood pressure, serum lipid levels, body fat, emotional stress, and cardiovascular mortality. Safety

is a primary issue when developing exercise programs for individuals with cardiac disease. Patients should be under the care of a physician and may require an exercise stress test to guide the exercise program design.

Hormonal Responses to Exercise

The endocrine system plays a major role in regulating the body's response to exercise and training by releasing various hormones via glandular secretion. After binding to specific receptors on a target cell, these hormones perform a number of functions in the body, such as regulating cellular metabolism, facilitating the cardiovascular responses to exercise, and modulating protein synthesis. The hormonal response to exercise is very complex, and the integrated response of the various systems provides the changes necessary to help the body make the acute and chronic adaptations to exercise training. A brief description of the major hormonal responses to exercise is presented below.

- **Growth hormone (GH)** is secreted by the anterior pituitary gland and facilitates protein synthesis in the body. Many effects of growth hormones are mediated by **insulin-like growth factors** (IGF I and IGF II), which are synthesized in the liver as a result of GH release during exercise.
- **Antidiuretic hormone (ADH),** which is also called **vasopressin,** is released by the posterior pituitary gland during exercise. As its name implies, its primary function is to reduce urinary excretion of water. By conserving water during exercise, it helps to prevent dehydration.
- **Epinephrine** and **norepinephrine** are called **catecholamines** and are released by the adrenal medulla. They are released as part of the sympathetic response to exercise (the "fight or flight" mechanism) and play two major roles. One role is to increase cardiac output by increasing heart rate and contractility during exercise. The second role is to cause **glycogenolysis** (glycogen breakdown) in the liver, so that more glucose can be released into the bloodstream for use by the actively working muscles.
- **Aldosterone** and **cortisol** are two of the main hormones released by the adrenal cortex. Aldosterone plays a role in limiting sodium excretion in the urine, which serves to maintain electrolyte balance during exercise. Cortisol is a glucocorticoid and plays a major role in maintaining blood glucose during prolonged exercise by promoting protein and triglyceride breakdown.
- **Insulin** and **glucagon** are both secreted by the cells of the **islets of Langerhans** in the pancreas, yet they have opposite effects. When blood glucose is high (e.g., after a meal), insulin is released from the **beta cells** in the islets of Langerhans to facilitate glucose removal from the blood and return blood glucose to a normal range. When blood glucose levels are low (e.g., during prolonged endurance exercise), glucagon is released from the **alpha cells** in the islets of Langerhans to stimulate glucose release from the liver to increase blood glucose. Glucagon also causes the release of free fatty acids from adipose tissue so that they can be used as fuel.
- **Testosterone** (released by the testes) and **estrogen** (released by the ovaries) are the primary male and female sex hormones, respectively. Testosterone is responsible for the masculine characteristics associated

with manhood (**androgenic** effects) and also has **anabolic** (muscle-building) effects. Because of their potent anabolic effects, testosterone and its derivatives are often abused in attempts to enhance athletic performance. Estrogen is responsible for the feminine characteristics associated with being a woman and also plays a major role in bone formation and maintenance. High levels of chronic exercise training have been shown to decrease estrogen levels to the point where some female athletes no longer have their menstrual cycle (**amenorrhea**). Amenorrhea has been associated with **osteoporosis** and increased risk of bone fractures.

Environmental Considerations When Exercising

Exercising under extreme environmental conditions can add significant stress to the cardiovascular system. Special precautions need to be taken when exercising in the heat or cold, at high altitude, or in the presence of pollution.

Exercising in the Heat

Considerable metabolic heat is produced during exercise. To reduce this internal heat load, venous blood is brought to the skin surface (peripheral vasodilation) to be cooled. When the sweat glands secrete water onto the skin, it is evaporated, which serves to cool the underlying blood. If environmental conditions are favorable, these mechanisms will adequately prevent the body temperature from rising more than about 2 to 3° F, even during heavy exercise.

When exercising in the heat, however, dissipating internal body heat is difficult, and external heat from the environment may significantly add to the total heat load. This results in a higher-than-normal heart rate at any given level of exercise. For example, if someone walks at 3 miles per hour and their heart rate is normally 125 beats per minute, walking at the same speed in the heat may result in a heart rate of 135 to 140 beats per minute. Thus, exercisers (regardless of the type of exercise performed) need to decrease their absolute workload in the heat to stay within their target HR zone.

This elevated HR comes about primarily for two reasons. First, as the body tries to cool itself, the high degree of vasodilation in the vessels supplying the skin reduces venous return of blood to the heart and SV declines. The heart attempts to maintain cardiac output by elevating HR. Second, sweating results in a considerable loss of body water. If lost fluids are not replenished, dehydration eventually results, and blood volume declines. This will also decrease venous return to the heart. Again, the body responds with a higher HR to maintain cardiac output.

The most stressful condition in which to exercise is a hot, humid environment. When the air contains a large quantity of water vapor, sweat will not evaporate readily. Since it is the evaporative process that cools the body, adequate cooling may not occur in humid conditions. Under these conditions, heat exhaustion and heat stroke become dangerous possibilities. Heat exhaustion usually develops in unacclimatized individuals and is typically a combination of inadequate circulatory adjustments to exercise coupled with fluid loss. Heat stroke is a complete failure of the heat-regulating mechanisms, with core temperature exceeding 105° F (41° C). Both conditions require immediate medical attention. Symptoms of heat exhaustion and heat stroke, as well as treatment options, are presented in Table 1.2. Table 1.3 combines measures of heat and humidity

Table 1.2
Heat Exhaustion and Heat Stroke

	Signs and Symptoms	Treatment
Heat Exhaustion	Weak, rapid pulse Low blood pressure Headache Nausea Dizziness General weakness Paleness Cold clammy skin Profuse sweating Elevated body core temp (<104° F or 40° C)	Stop exercising Move to a cool, ventilated area Lay down and elevate feet 12–18 inches Give fluids Monitor temperature
Heat Stroke	Hot, dry skin Bright red skin color Rapid, strong pulse Labored breathing Elevated body core temp (>105° F or 41° C)	Stop exercising Remove as much clothing as feasible Try to cool body immediately in any way possible (wet towels, ice packs/baths, fan, alcohol rubs) Give fluids Transport to emergency room immediately

Table 1.3
Heat Index

	TEMPERATURE (°F) (°C given in parentheses)										
	70 (21)	75 (24)	80 (27)	85 (29)	90 (32)	95 (35)	100 (38)	105 (41)	110 (43)	115 (46)	120 (49)
RELATIVE HUMIDITY %	APPARENT TEMPERATURE* (°F) (°C given in parentheses)										
0	64 (18)	69 (21)	73 (23)	78 (26)	83 (28)	87 (31)	91 (33)	95 (35)	99 (37)	103 (39)	107 (42)
10	65 (18)	70 (21)	75 (24)	80 (27)	85 (29)	90 (32)	95 (35)	100 (38)	105 (41)	111 (44)	116 (47)
20	66 (19)	72 (22)	77 (25)	82 (28)	87 (31)	93 (34)	99 (37)	105 (41)	112 (44)	120 (49)	130 (54)
30	67 (19)	73 (23)	78 (26)	84 (29)	90 (32)	96 (36)	104 (40)	113 (45)	123 (51)	135 (57)	148 (64)
40	68 (20)	74 (23)	79 (26)	86 (30)	93 (34)	101 (38)	110 (43)	123 (51)	137 (58)	151 (66)	
50	69 (21)	75 (24)	81 (27)	88 (31)	96 (36)	107 (42)	120 (49)	135 (57)	150 (66)		
60	70 (21)	76 (24)	82 (28)	90 (32)	100 (38)	114 (46)	132 (56)	149 (65)			
70	70 (21)	77 (25)	85 (29)	93 (34)	106 (41)	124 (51)	144 (62)				
80	71 (22)	78 (26)	86 (30)	97 (36)	113 (45)	136 (58)					
90	71 (22)	79 (26)	88 (31)	102 (39)	122 (50)						
100	72 (22)	80 (27)	91 (33)	108 (42)							

How to Use Heat Index

1. Locate temperature across top
2. Locate relative humidity down left side
3. Follow across and down to find Apparent Temperature
4. Determine Heat Stress Risk on chart at right

Note: This Heat Index chart is designed to provide general guidelines for assessing the potential severity of heat stress. Individual reactions to heat will vary. In addition, studies indicate that susceptibility to heat disorders tends to increase among children and older adults. Exposure to full sunshine can increase Heat Index values by up to 15° F.

Apparent Temperature		Heat Stress Risk with Physical Activity and/or Prolonged Exposure
90–105	(32–41)	Heat cramps or heat exhaustion *possible*
105–130	(41–54)	Heat cramps or heat exhaustion *likely* Heat stroke *possible*
130–151	(54–66)	Heat stroke *highly likely*

*Combined index of heat and humidity and what it feels like to the body

into a simple-to-use **heat index.** The heat index provides guidelines regarding when exercise can be safely undertaken, and when it should be avoided.

Below are some additional tips for exercising in the heat:

- **Begin exercising gradually in the heat.** Becoming acclimatized to exercising in the heat takes approximately one week to 10 days. Start by exercising for short periods of time each day.
- **Always wear lightweight, well-ventilated clothing.** Cotton materials are cooler; most synthetics retain heat. Wear light-colored clothing if exercising in the sun; white reflects heat better than other colors.
- **Never wear impermeable or nonbreathable garments.** The notion that wearing rubber suits or nonbreathable garments adds to weight loss is a myth. Wearing impermeable clothing is a dangerous practice that could lead to significant heat stress and heat injury.
- **Replace body fluids as they are lost.** Drink fluids at regular intervals while exercising, but avoid overhydration, which, although relatively rare, can be as dangerous as dehydration. Frequent consumption of small amounts of fluid, designed to minimize sweat-related weight loss, is the best approach.
- **Recording daily body weight is an excellent way to prevent accumulative dehydration.** For example, if 5 pounds (2.25 kg) of body water is lost during aerobic exercise, this water should be replaced before exercising again the next day. If lost water has not been regained, exercise should be curtailed until the body is adequately rehydrated.

Exercising in the Cold

The major problems encountered when exercising in the cold are associated with an excessive loss of body heat, which can result in hypothermia or frostbite. Additionally, the cold can cause a generalized vasoconstriction that can increase peripheral resistance and blood pressure. This may cause problems in people who are hypertensive or who have heart disease. Following exercise, chilling can occur quickly if the body surface is wet with sweat and heat loss continues.

Heat loss from the body becomes greatly accelerated when there is a strong wind. The windchill factor can be quite significant. Similar to the heat index chart, Table 1.4 provides the various combinations of temperature and wind velocity that can be used as guidelines when deciding if it is safe to exercise in the cold.

Below are some additional tips for exercising in the cold:

- **Wear several layers of clothing.** By layering clothing, an exerciser can remove and replace garments as needed. When exercise intensity is high, remove outer garments. Then, during periods of rest, warm-up, cool-down, or low-intensity exercise, put them back on. A head covering is also important, because considerable body heat radiates from the head.
- **Allow for adequate ventilation of sweat.** Sweating during heavy exercise can soak inner garments. If evaporation does not readily occur, the wet garments will continue to drain the body of heat during rest periods, when retention of body heat is important.
- **Select garment materials that allow the body to give off body heat during exercise and retain body heat during inactive periods.** Cotton is a good choice for exercising in the heat because it readily soaks up sweat and allows evaporation; for those same reasons, however, cotton is a poor choice for exercising in the cold. Wool is an excellent choice when exercising in the

Table 1.4
Windchill Factor Chart

Estimated wind speed (in mph) (km/h given in parentheses)	ACTUAL THERMOMETER READING (°F) (°C given in parentheses)											
	50 (10)	40 (4)	30 (-1)	20 (-7)	10 (-12)	0 (-18)	-10 (-23)	-20 (-29)	-30 (-34)	-40 (-40)	-50 (-46)	-60 (-51)
	EQUIVALENT TEMPERATURE (°F) (°C given in parentheses)											
calm	50 (10)	40 (4)	30 (-1)	20 (-7)	10 (-12)	0 (-18)	-10 (-23)	-20 (-29)	-30 (-34)	-40 (-40)	-50 (-46)	-60 (-51)
5 (8)	48 (9)	37 (3)	27 (-3)	16 (-9)	6 (-14)	-5 (-21)	-15 (-26)	-26 (-32)	-36 (-38)	-47 (-44)	-57 (-49)	-68 (-56)
10 (16)	40 (4)	28 (-2)	16 (-9)	4 (-16)	-9 (-23)	-24 (-31)	-33 (-36)	-46 (-43)	-58 (-50)	-70 (-57)	-83 (-64)	-95 (-71)
15 (24)	36 (2)	22 (-6)	9 (-13)	-5 (-21)	-18 (-28)	-32 (-36)	-45 (-43)	-58 (-50)	-72 (-58)	-85 (-65)	-99 (-78)	-112 (-80)
20 (32)	32 (0)	18 (-8)	4 (-16)	-10 (-23)	-25 (-32)	-39 (-39)	-53 (-47)	-67 (-55)	-82 (-63)	-96 (-71)	-110 (-79)	-124 (-87)
25 (40)	30 (-1)	16 (-9)	0 (-18)	-15 (-26)	-29 (-34)	-44 (-42)	-59 (-51)	-74 (-59)	-88 (-67)	-104 (-76)	-118 (-83)	-133 (-92)
30 (48)	28 (-2)	13 (-11)	-2 (-19)	-18 (-28)	-33 (-36)	-48 (-44)	-63 (-53)	-79 (-62)	-94 (-70)	-109 (-78)	-125 (-87)	-140 (-96)
35 (56)	27 (-3)	11 (-12)	-4 (-20)	-20 (-29)	-35 (-37)	-51 (-46)	-67 (-55)	-82 (-63)	-98 (-72)	-113 (-81)	-129 (-89)	-145 (-98)
40 (64)	26 (-3)	10 (-12)	-6 (-21)	-21 (-29)	-37 (-38)	-53 (-47)	-69 (-56)	-85 (-65)	-100 (-73)	-116 (-82)	-132 (-91)	-146 (-99)
[Wind speeds greater than 40 mph (64 km/h) have little additional effect.]	GREEN				YELLOW				RED			
	LITTLE DANGER (for properly clothed person). Maximum danger of false sense of security.				INCREASING DANGER Danger for freezing of exposed flesh.				GREAT DANGER			

cold because, even when it is wet, it maintains body heat. Newer, synthetic materials (e.g., polypropylene) are also excellent choices, as they wick sweat away from the body, thus preventing heat loss. When windchill is a problem, nylon materials are good for outerwear. Gore-Tex®-like materials, although much more expensive than nylon, are probably the best choice for outerwear because they can block the wind, are waterproof, and allow moisture to move away from the body.

• **Replace body fluids in the cold, just as in the heat.** Fluid replacement is vitally important when exercising in cold air. Large amounts of water are lost from the body during even normal respiration and this effect becomes magnified when exercising. Because sweat losses may not be as obvious as when exercising in the heat, monitoring of body weight over several days is recommended. (See Chapter 4 for recommended fluid intakes.)

Exercising at Higher Altitudes

At moderate-to-high altitudes, the **partial pressure*** of oxygen in the air is reduced. Because there is less pressure to drive the oxygen molecules into the blood in the lungs, the oxygen carried in the blood is reduced. Therefore, a person exercising at high altitude will not be able to deliver as much oxygen to the exercising muscles and exercise intensity will have to be reduced (e.g., the person will have to walk or run slower) to keep his or her HR in a target zone.

Signs and symptoms of altitude sickness include shortness of breath, headache, light-

* Partial pressure is the pressure of each gas in a multiple-gas system such as air, which is composed of nitrogen, oxygen, and carbon dioxide.

headedness, and nausea. Generally, altitude sickness can be avoided by acclimatizing oneself properly. This means gradually increasing exercise and activity levels over the span of several days. Using a prolonged warm-up and cool-down and incorporating frequent exercise breaks at a lower intensity should help most people acclimate to exercising at higher altitudes.

Air Pollution

Some areas of the country have a high degree of airborne pollutants (smog) that can adversely affect exercise performance. These pollutants are the result of the combustion of fossil fuels and primarily include ozone, sulfur dioxide, and carbon monoxide. When these airborne particles are inhaled, they can have a number of deleterious effects on the body, such as irritating the airways and decreasing the oxygen-carrying capacity of the blood, both of which hamper performance. In individuals with cardiovascular disease, prolonged exposure to air pollution can even induce ischemia and angina. The overall physiological effects are determined by the degree (or dose) of pollutants to which an individual is exposed. This dose is related to the amount of pollutants in the air, the length of exposure, and the amount of air breathed. Practical suggestions to minimize the effects of air pollution include exercising early in the morning to avoid the build-up of pollutants associated with increased vehicular traffic, and avoiding high-traffic, urban areas. Similar to when exercising in the heat or at altitude, exercise pace may need to be reduced to keep HR in the appropriate training range. Under extreme conditions, exercising indoors is probably the best choice.

Summary

This chapter is designed to provide the group fitness instructor with basic principles of exercise physiology. Considerable space has been devoted to the presentation of aerobic and anaerobic metabolism, because the principle of specificity clearly dictates that physiological adaptations are specific to encountered stresses. The group fitness instructor must understand the various methods of applying progressive overload and the physiological adaptations that result. Too often, the exercising public falls victim to the poor advice of exercise teachers, coaches, and other "experts" who fail to apply the concept of exercise specificity because they simply do not understand basic principles.

A large amount of information has been given in a relatively small amount of space. The emphasis has been on basic understanding rather than on detailed explanation. Students of this material are strongly encouraged to seek further knowledge of exercise physiology and the principles of physical fitness and human movement through more advanced study.

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